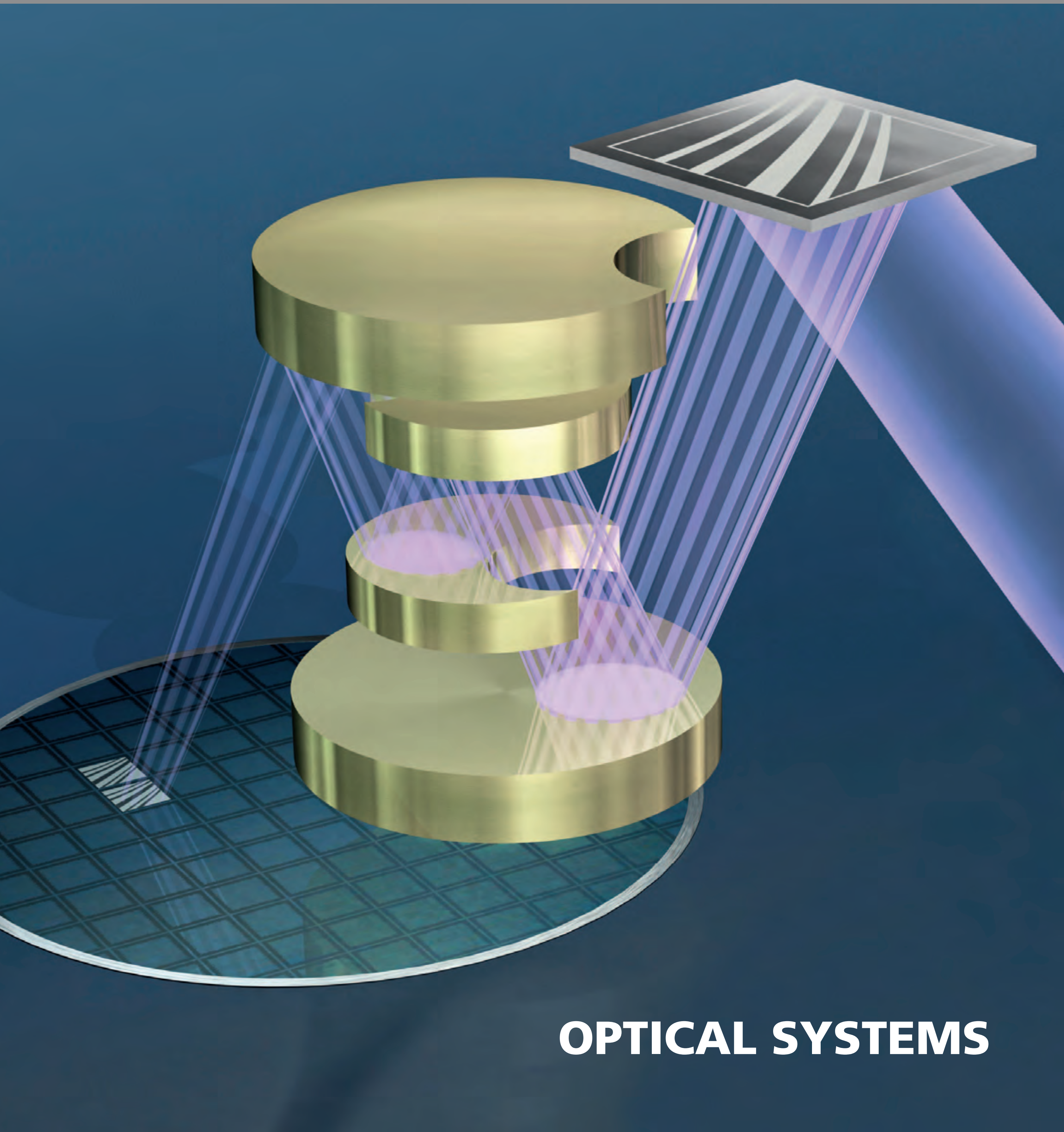
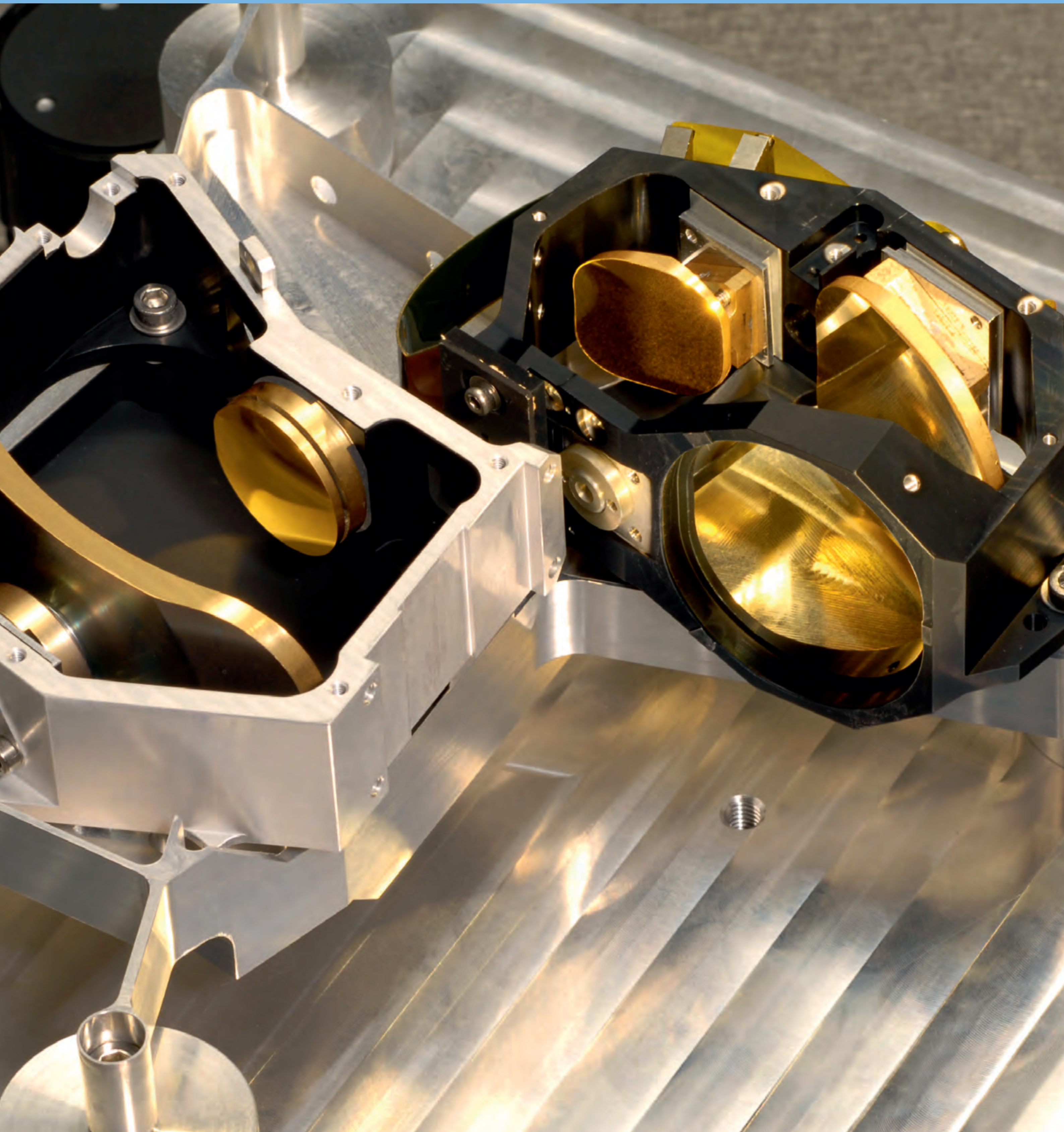
Fraunhofer
LIGHT & SURFACES

FRAUNHOFER GROUP LIGHT & SURFACES



OPTICAL SYSTEMS

OPTICAL SYSTEMS



OPTICAL SYSTEMS – KEY ENABLING TECHNOLOGY

The 21st century is the century of Photonics. Actually we are just at the beginning of an innovation cycle in Photonics. Today Photonics is at a threshold which is comparable with the shift from conventional electronics to microelectronics in the sixties.

Photonics will be the key technology for energy efficiency, communication, information, mobility, environment, food and health and thus important for future markets and mega trends. Photonics is a growing market which serves all these areas conductive and innovatively.

The Fraunhofer Group Light & Surfaces conducts application-oriented research in the field of optical systems engineering on behalf of its clients in industry and within government collaborative research projects.

Our objective is to develop innovative optical systems to control light, from its generation to its application in the cutting-edge fields of energy, environment, information, communication, healthcare, production, safety, and mobility. To achieve these goals, the Fraunhofer Group Light & Surfaces charts the entire process chain, from the system design to the manufacture of prototype optical, opto-mechanical and opto-electronic systems.

We look forward to help you to strengthen your market position with innovative optical systems.

COVER *Principle of EUV lithography (© Fraunhofer IWS).*
LEFT *Optical assembly of the thermal IR-spectrometer MERTIS (© Fraunhofer IOF).*

CONTENT

DESIGN, SIMULATION, ANALYSIS, AND MODELING

The key areas of expertise and the basis for optical system development at the Fraunhofer Group Light & Surfaces are design, simulation, and analysis of optical and opto-mechanical systems. Extensive design and modeling tools enable the optimization of systems for the THz to X-ray range – from micro-optics to macro-optics such as astronomical telescopes.

OPTICAL DESIGN

Optical design encompasses the entire spectrum from diffractive and refractive optical elements all the way to components for integrated optics. In particular, this includes free-form optics as well as systems which combine micro-optical and conventional optical components. Based on our know-how we offer for your demands:

- Design and conception of complex optical and micro-optical components and systems
- Raytracing and wave optics design
- Diffractive and refractive optics
- Design of free-form optics
- Waveguide design
- Design of optical layer systems
- Spectral regions: X-ray – EUV – VIS – IR – THz
- Tolerancing

We use state-of-the-art commercially available optical design software based on conventional geometrical ray optics (including free-space wave propagation, FDTD, raytracing) up to rigorous methods of wave optics. If required, specific add-on's like macros and interfaces extend the capabilities of these design tools. This enables us to support our customers with the design of all kinds of optical, micro-optical, and nano-optical components and systems. We consider all requirements and demands our customers have on their system to be designed. Already within the design phase available manufacturing methods and their manufacturing tolerances are considered. Thus, at the end of the design phase, our customer will get an optical design that fulfills the state of the scientific and technical knowledge and which is producible. The Fraunhofer Group Light & Surfaces assists the customer in manufacturing his systems or prototypes or arranges contacts to industrial partners.

In addition, we support our customers with all our competences in the fields of:

- Assistance all the way to the prototype
- Customized macro-programming
- Customer-tailored software

Contact: A1 I A3 I A5

MECHANICAL DESIGN AND SIMULATION

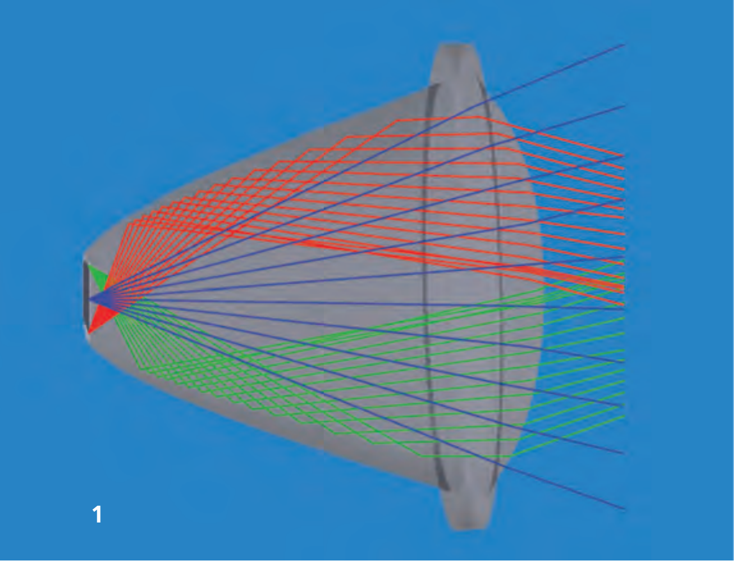
The quality of optical systems depends not only on the quality of the optical components, but also on their mounting and adjusting. Mechanical design and simulation is also necessary to ensure that the complete system can resist extreme environmental conditions (temperature, acceleration, gravity, and much more). This includes optimization in the mounting of optical components and the design of kinematic configuration. A further area of focus is the thermal design of optical systems, aimed at making these insensitive to temperature influences from the environment or to thermal lenses in high-performance applications.

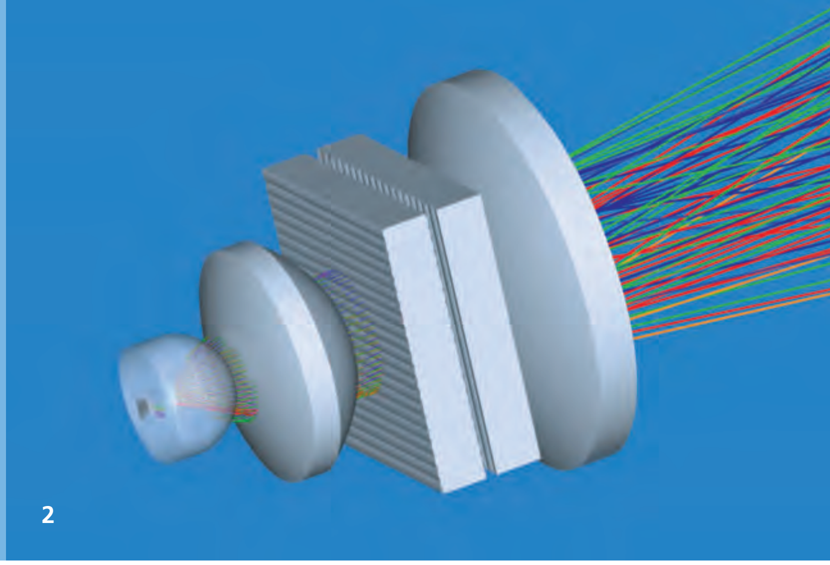
Contact: A2

SIMULATION OF COATING PROCESSES

Coatings are often of essential importance for the realization of specific functions. The knowledge of coating processes and the machines making them is important to improve their quality. By the use of particle-in-cell Monte-Carlo simulations, complete deposition processes can be simulated and developed. This includes plasma-based deposition processes (sputtering) as well as evaporation processes.

Contact: A5





SIMULATION OF OPTICAL FUNCTIONS

The Fraunhofer Group Light & Surfaces carries out optical and mechanical simulations and analyses of components and systems. A variety of functions and processes are addressed:

- Simulation of optical functions
- Analysis of complex optical systems
- Analysis of scattered and stray light (including light scattering measurements)
- Organic Light Emitting Diode (OLED) simulation and analysis
- Waveguide Analysis
- Free-form design
- Analysis of fiber laser systems
- Complex analysis of optical systems e.g. thermal analysis, tolerancing, stray light, cost estimation
- Characterization of optical elements and systems
- Control of object adjustment and assembling

We perform all the simulations and – if necessary – the appropriate measurements. All data are finally included in one model function and are evaluated. Thus the customer gets detailed data on the considered system. Most of the performance values of the optical system can be evaluated before a complete prototype is realized.

Contact: A3 I A4

1 *Design of a TIR-concentrator (© Fraunhofer IOF).*

2 *Micro-optical beam shaping optics for LED illumination (© Fraunhofer IOF).*

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SYSTEM INTEGRATION AND ASSEMBLY

The Fraunhofer Group Light & Surfaces possesses extensive expertise in the development of technologies for the integration of diverse components with high precision for complex opto-mechanical and opto-electronical micro- and macrosystems. This encompasses assembly technologies (positioning, aligning), joining technologies (bonding, laser soldering, plasma bonding, laser splicing, alignment turning) and the integration of optical systems.

SYSTEM INTEGRATION

Optical Systems do not only contain optical components and mechanical mounts, but also electronical components to drive active elements, thermo-electrical components for temperature control, actuators to induce motions, and many more. Beside the main optical functionality a convincing integration determines the stability and accuracy of the optical performance; it also influences efficiency and the cost structure of complex opto-electromechanical systems.

High performance integration approaches are developed which are based on multifunctional system platforms made of ceramics or glass ceramics. These provide at first a very stable base for the mounting of optical components. Due to various available mechanical structuring methods the platforms also contain mounting geometries in which optical components can be precisely assembled. Thick and thin film structuring allows for wiring and electrical component integration, in case of Low Temperature Cofired Ceramics (LTCC) also by using multilayer technologies. Active and passive thermal elements such as fluidic channels or locally good heat conducting geometries are also part of our portfolio.

The assembly of those integrated optical systems can be carried out at least partially on wafer level. Therefore pick&place technologies can be adapted for merging manufacturing of optics and electronics.

Contact: B2 I B3 I B4

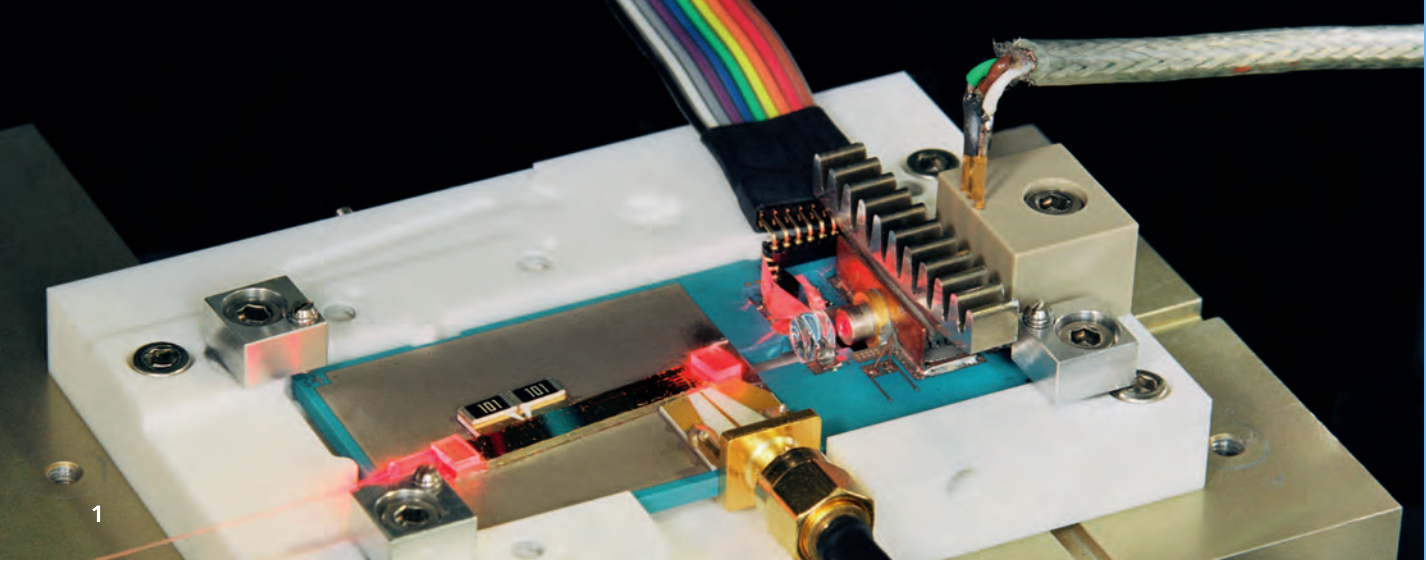
ASSEMBLY AND PACKAGING TECHNOLOGIES

The performance of optical systems depends strongly on the quality of the assembly and mounting of the different components. Thus optics, mechanics, electronics, and more has to be stable and robustly integrated in a final system to withstand ambient conditions. The tolerancing of the mounting has to follow the specifications of the optical design. Classical assembly and packaging technologies (positioning, aligning, pick & place, pick-up tools) can be used for multiple systems.

Miniaturized optical systems are increasingly characterized by a high complexity, since the optical components with electronic components and systems for micromechanical actuators have to be associated with high integration density. Special technologies, for example on wafer level, have to be used to fulfill highest quality and economical realization.

Contact: B1

1 *Optoelectronical system integration (© Fraunhofer IOF).*



1

JOINING TECHNOLOGIES

The bonding technologies used in microassembly influence the accuracy of the positioned component as well as the longterm- and temperature stability of the assembly.
We analyse and simulate these joints with the help of Finite Element Method (FEM) tools and investigates adhesive bonding laserbeam soldering and mechanical clamping (snap in) to be able to adapt these bonding technologies to custom assemblies. Innovative soldering and bonding procedures enable us to mount all the optical components like mirrors, lenses and crystals by means of automated processes with high precision, long-term stability, and cost-effectiveness.

For these purposes we use bonding (including plasma activation for low-temperature bonding), laser soldering, laser splicing, alignment turning, solderjet bumping for the assembly of micro-optical systems, bonding technologies adapted to glass and glass-ceramics, and soldering - a packaging technology for stable optical systems.

Contact: B1

HYBRID INTEGRATION

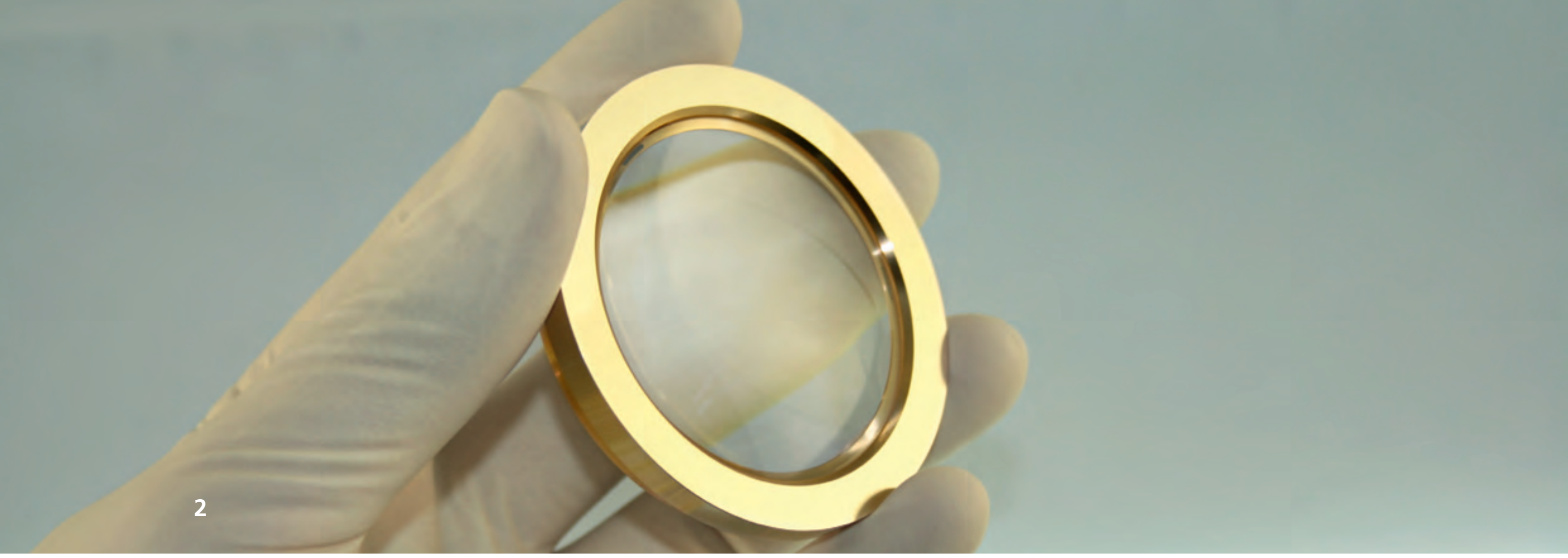
Lithography, dry etching as well as UV molding are characterized by good lateral precision. So the pitch of a lens array can be matched to that of another or to arrays of fibers, detectors, or lasers being a prerequisite for the generation of microoptical systems. Furthermore, an integration on wafer scale becomes feasible.

Typical examples are the following:

- Ultra Violet (UV) molding on top of a wafer carrying detectors or Vertical-cavity surface-emitting lasers (VCSELs)
- Multifunctional elements fabricated by combination of technologies
- Double-sided UV molding in a mask aligner
- Double-sided elements fabricated by dry etching
- Surface coating (involving anti-reflection coatings), but also the integration of filters, beam splitters etc.
- Generation of electrode patterns
- Integration of diaphragms/apertures made with metal as well as with black polymer

The last process step in the process is the segmentation of the wafer into a high number of micro-optical (sub-)systems.

Contact: B1



2

HEAT SINK DESIGN

We develop cooling concepts and heat sinks for high-performance diode lasers. Today we concentrate on developing expansion-adapted heat sinks, increasing life time and reducing costs. For this, we investigate and develop passive as well as active heat sinks. Particularly in the sector of thermal design, we have gained significant experience in the last few years, which flows also into the development of heat sinks for solid state lasers.

We offer our customers a wide spectrum of R&D services for the design and optimization of heat sinks under the aspect of thermal modeling (FEA) and simulation of fluids (CFD), the identification of the thermal expansion coefficient by means of speckle interferometry and the identification and analysis of thermal resistance.

Using in-house developed burn-in systems, we conduct tests to identify life times of high-performance diode lasers, whereby we investigate nearly all the required test parameters in continuous and pulsed operation at different temperatures.

Contact: B1 / B5

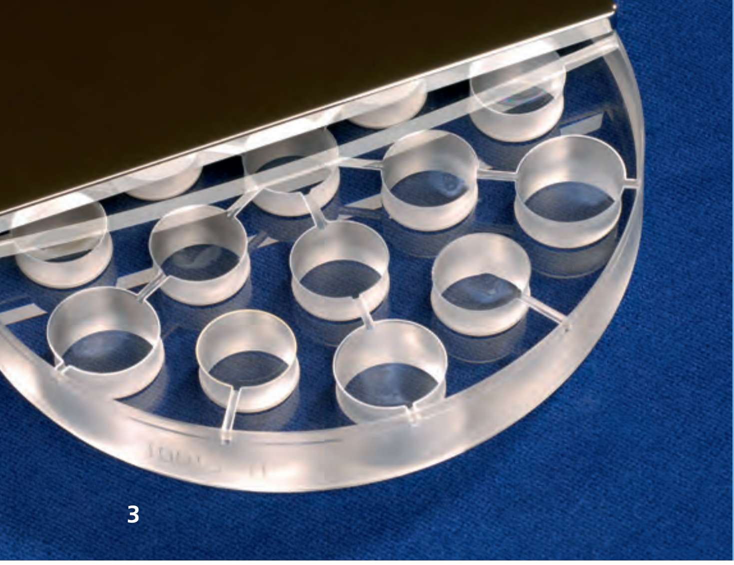
HANDLING, POSITIONING, ALIGNMENT

For a mechanized or automated micro assembly a fundamental requirement is the development of handling procedures that are not only suitable for the precise gripping, positioning and aligning of small and often very sensitive components, but also able to work in production environments for a high number of assembled devices with similar high quality.

Microsystems and especially microoptical systems often demand positioning accuracies in up to six degrees of freedom in the micron- and submicron-range for components within an assembly. At the Fraunhofer Group Light & Surfaces the analysis and optimization of positioning technologies is carried out with the help of different positioning systems that travel in a range up to 400 mm x 200 mm with a bidirectional accuracy of 0.3 micron. Robots and hexapod systems aid the precise positioning of components and assembly tools like grippers, cameras, and joining equipment.

Contact: B3

2 *Adhesive-free and low-stress laser soldered lens with alignment turned mount (© Fraunhofer IOF).*
3 *Light-weight composite (plain-concave) in "sandwich" structure (top side silicate bonded) (© Fraunhofer IOF).*
4 *Laser bonding (© Fraunhofer IOF).*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4

WAFER-LEVEL-OPTICS

Micro-optical imaging systems differ from conventional camera set-up in the degree of their miniaturization and consequently their production technologies.

For handling reasons during processing and demands for cost-effective manufacturing, extensive parallelized production methods at wafer level are used. Areas of research are for example: optical design, boundary conditions of component manufacture, construction, and joining technology and coupling to electronic image converters. Wafer-level optics are for example used for multi-aperture camera-optics (ultra-thin camera) or single-aperture imaging systems.

Contact: B2

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IMAGING AND ILLUMINATION

Modern optical systems, for example in the fields of illumination and imaging, require adapted and highly efficient solutions. The Fraunhofer Group Light & Surfaces develops illumination and beam control systems for lasers, Light Emitting Diodes (LEDs) and OLEDs (organic LEDs) as well as miniaturized digital projection systems and ultracompact imaging systems.

LED- AND OLED-OPTICS

Decoupling and beam-shaping optics for LEDs and OLEDs transport light from the source to the application. Applied designs for collimators and diffusers enable the use of the benefits of LEDs and OLEDs such as high conversion efficiency, useful life time, and controllable color.

Modern high-performance LEDs enable new approaches for efficient lighting systems. With adapted optics, all kinds of light distribution can be generated depending on the application. Optimized LED illumination is, for instance, needed for special measurement and imaging requirements.
For such applications, we use microlens arrays, freeform optics, and complex microoptic modules; realizable in different materials, such as fused silica, borosilicate glass, and silicon.

OLEDs are new light sources which, on account of the continuous spectrum, the large luminous area and low thickness fundamentally differ from conventional (spot) light sources. Adjusting the radiation field to the specific tasks of measurement or general lighting requires special microoptical approaches which take into account the flat design and maintain the attractive properties of OLEDs. Additionally, we offer optical characterization and optimization of OLEDs for example with tailoring the light emission pattern.

Contact: C2 I C5

LED ILLUMINATION SYSTEMS

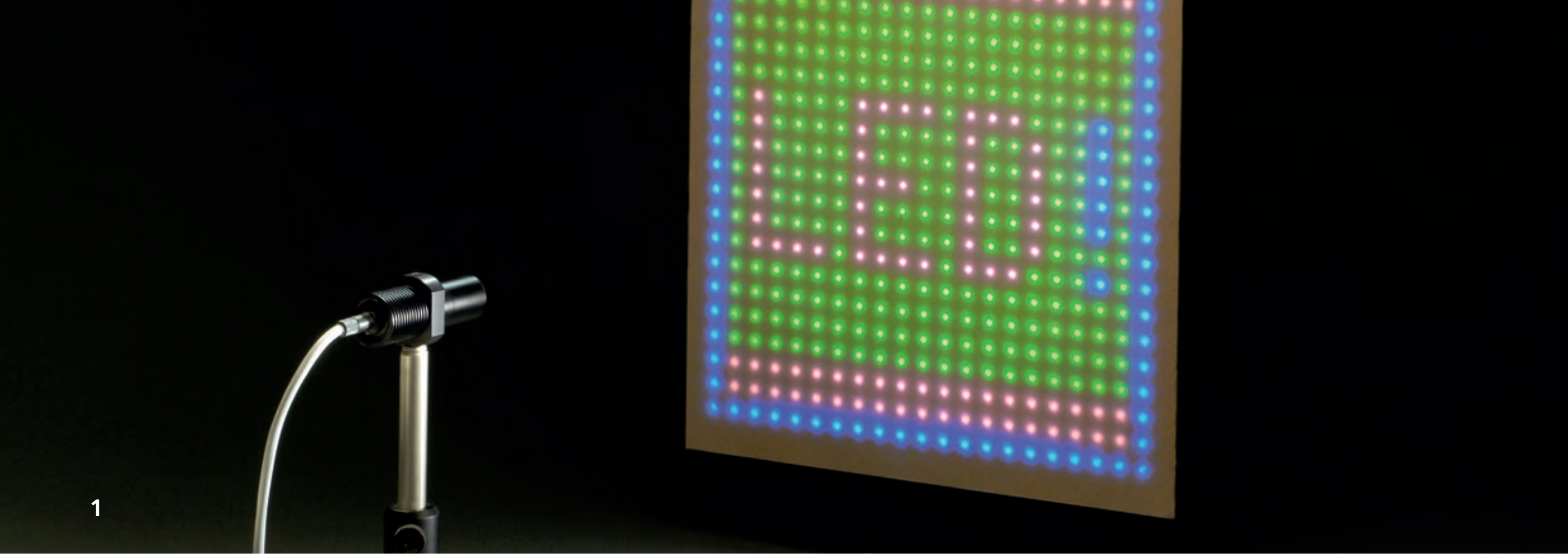
To use of the benefits of modern LED technology in general lighting (including high electro-optical conversion efficiency) controllable color, and long useful life is necessary.

The required optics is usually composed of a collimating and a beam shaping element. Efficient collimation is achieved with concentrators, while beam shaping fly´s eye condensers provide homogeneous illumination of circular, square, or oblong areas or line foci. These homogenizers are realized with tandem microlens arrays, providing high system transmission, minimum loss of etendue, and very short system length.

Straylight suppression for hexagonally packed circular lenslet arrays is achieved by buried absorbing aperture arrays. Actually, precise free-form optics is often used to transform the radiation patterns of the LEDs, e.g. the far-field distribution needs to be adapted for street lighting applications. We use these microoptics for LED-beam shaping to realize high-efficient LED-illumination devices. The LED optics are mostly manufactured by injection molding or hot embossing of plastics or glass. For prototyping, direct diamond-turning of PMMA offers short development cycle times. Replication is carried out by injection molding or by UV-curing into polymer on both sides of a float glass substrate wafer. The Fraunhofer Group Light & Surfaces conducts the customers from the design over the prototype to production technologies.

Contact: C1 I C5

1 *LED spot array generator operational (© Fraunhofer IOF).*



1

MICROOPTICAL CAMERAS AND MICROSCOPES

Microoptical imaging systems, in contrast to conventional imaging systems, differ regarding the level of miniaturization and manufacturing methods. Processes of parallelized production at wafer-level scale are for inexpensive production. The optical design, the constraints of the component production, the assembly and joining technology, and the installation to the electronic imager strongly depend on each other.

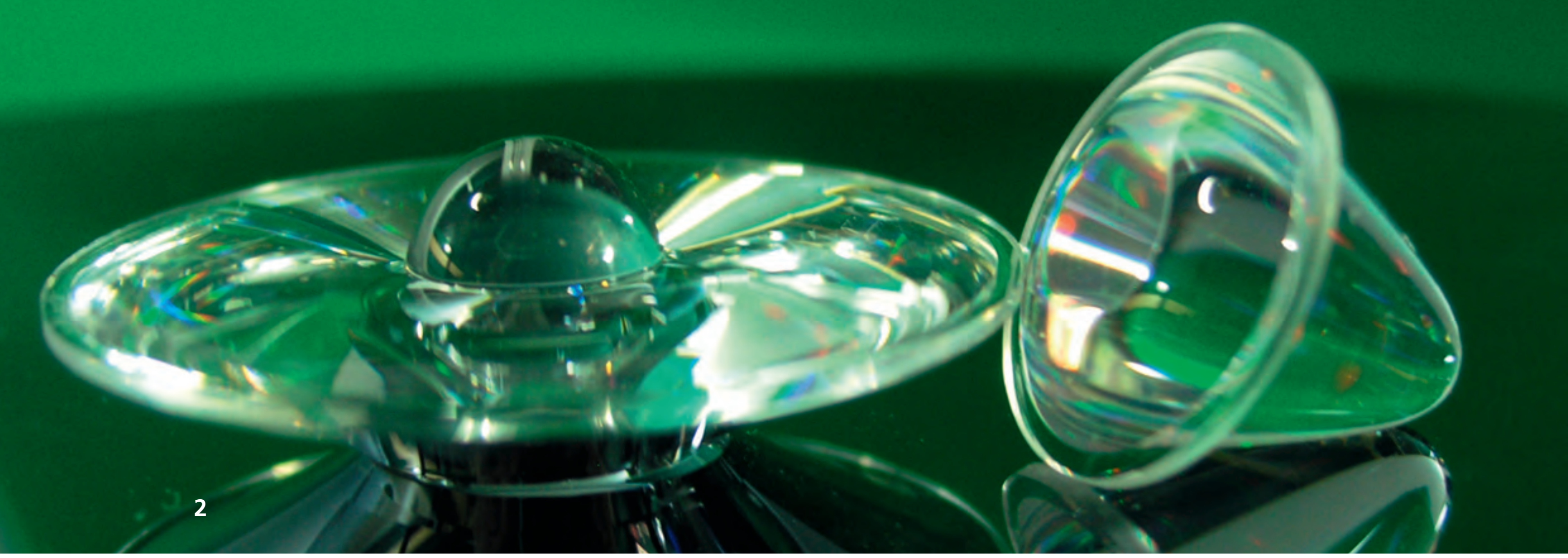
Conventional (single aperture) objectives transmit the entire object field through a single aperture and resemble the human eye. In contrast, multi-aperture objectives possess a multitude of adjacently-placed neighboring imaging channels, each transmitting a part of the overall object. Later, the pictures are assembled to an overall picture. Having the overall height in contrast to single-aperture objectives at the same resolution and pixel size is achievable.

Systems and components based on wafer-level-production processes made of glass, polymer, and GRIN lenses are available. The fabrication of the required micro-lenses is based on the UV-replication of polymers, where a master wafer of the micro-lens arrays has been fabricated by binary mask lithography and reflow of the photoresist.

Close-up imaging system provides two new features in microscopic application: first, the reduction of the total track length down to about 5 mm, and second, the simultaneous examination of large object fields of almost arbitrary lateral extent with a spatial resolution of 5 µm. The imaging optics is based on aspherical and achromatic micro-lens arrays where each channel transmits a part of the entire object. The design of the system provides the stitching of the partial images, so that a seamless image is formed.

To realize these microoptical imaging systems, the Fraunhofer Group Light & Surfaces has the complete necessary technological chain available. We offer wafer-scale processes on thin glass substrates, master generation using lithography reflow and reactive ion etching, double-sided aligned UV-molding, integration of vertical illuminator based on a planar light guide without increasing the z-height, and integration of filters for fluorescence detection systems.

Contact: C5



2

PROJECTION SYSTEMS

In realizing customized microoptical and digital projection systems, the Fraunhofer Group Light & Surfaces covers all stages from the idea to the optical design, construction and prototype production to small-quantity production and transition to series production. Projection systems with micro displays (DLP, LCOS, LCD, OLED) as imaging elements are not just used in multimedia but also in medical technology, measurement technology, automotive engineering, simulators, and (manifold) other areas.

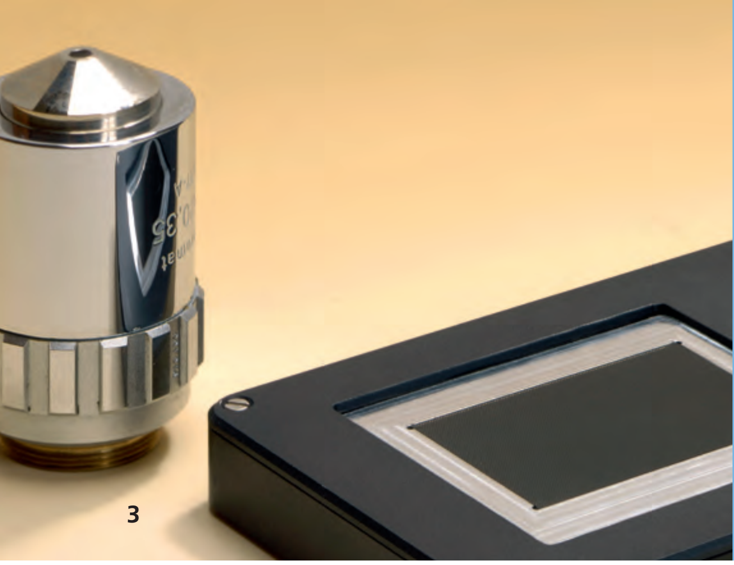
Displays – especially microdisplays – need optics for their use in many applications. The optic can be directly placed on the display e.g. to enhance the efficiency of the display or to avoid unwanted reflections. Or optic is used to integrate the display in complex optical systems, e.g. projection units. In all these areas we can help customers to find an optimal solution.

In addition, we offer general advisory service and draw up drafts about microdisplay applications. We report on actual technical developments, and help to select the most suitable and available displays. In contrast to projection optics, the Fraunhofer Group Light & Surfaces also supplies illumination optics and color/polarization management systems like

- Ultra-slim projection optics for structured illumination (array projector)
- Array projector "light tile"
- Micro laser projector
- Head-mounted display
- OLED-based near-to-eye stimulation system

Contact: C3 I C4 I C5

2 *Diamond-turned prototypes of refractive or reflective and simple TIR concentrator (© Fraunhofer IOF).*
3 *Completely assembled demonstrator of the ultra-thin microscope using a full format image sensor with a light sensitive area of 36 × 24 mm² having 16 million pixels (© Fraunhofer IOF).*
4 *3D camera based on laser scanners and micro mirrors (© Fraunhofer IPM).*



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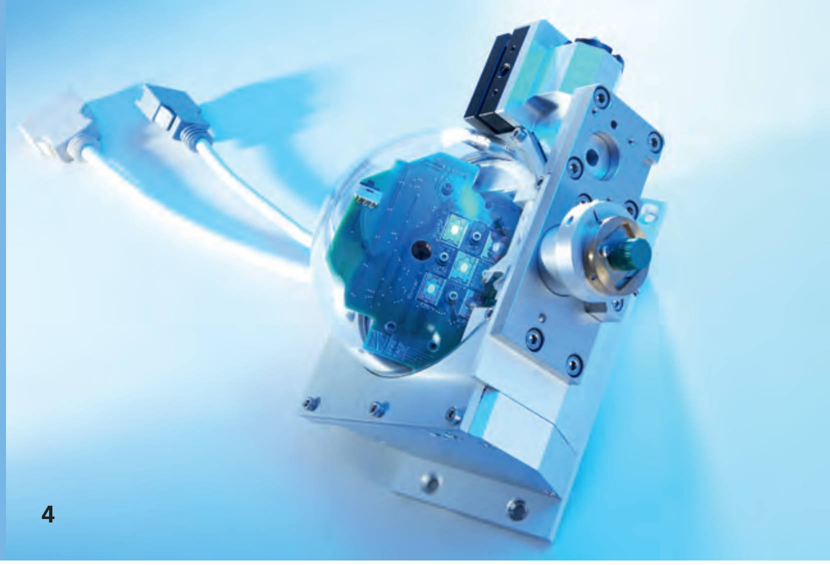

4

HEAD MOUNTED DISPLAYS (HMD)

Visual superposition of the real-world environment and displayed information, known as augmented reality, can be used in a multitude of applications ranging from tourist guidance to surveillance applications and support for service engineers.

See-through HMD are a key technology for utilization of augmented reality. Basic components which form such an HMD are the microdisplay and near-to-eye projection optics. Active OLED displays are attractive candidates for the microdisplay because of their small physical dimensions and low mass. To make these advantages effective, small, and light-weight projection optics with a low f-number and large field-of-view are required. Thus freeform prisms, which fold the optical path and combine a number of surfaces with optical power in a single element, are a promising approach. The Fraunhofer Group Light & Surfaces covers all stages of the optical realization of an HMD, from the optical and mechanical design, the realization of the freeform prisms, to the system integration.

Contact: C5

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PHOTONIC SENSORS AND MEASURING SYSTEMS

Light as an instrument of precision opens up a wide variety of possibilities for measurement, sensor, and analytics technology. Diverse optical and optoelectronic measuring and sensor systems are developed at the Fraunhofer Group Light & Surfaces. The spectrum ranges from process-integrated quality assurance, tracking and tracing system, 3D shape measurement via surface characterization to terahertz spectroscopy and computer tomography.

PROCESS CONTROL AND INSPECTION SYSTEMS

Tailored systems for non-destructive production control lead to higher efficiency in production. They replace traditional visual inspections and offer the possibility of a 100-percent quality control, even in rapid mass production processes.
Due to advanced optical technology, inspection in the micrometer range has become possible (with measurement frame rates up to 10 kHz) even in barely accessible sites.
We develop solutions for integrated process monitoring and control in close cooperation with equipment manufacturers. For different applications, we offer specialized and adapted solution, for example an industrial-suited, in-situ gas analytics for the quality assurance of chemical coating, control of deposition and etching processes using plasma emission lines, plasma characterization, etching and sintering processes, monitoring of emissions from industrial systems. We provide FTIR-based gas analytics systems even in highly particle loaded atmospheres. As a second example, camera based temperature measuring systems are available as a low-cost alternative in sophisticated laser processes like laser heat treatment and cladding. The integration in laser processing modules allows a permanent control and adjustment of relevant process parameters. Another inspection system for laser beam hardening processes is the camera-based constant monitoring and diagnosis of dynamically shaped laser beams even during the process.

Based on infrared spectroscopy, online analysis of optical plasma emissions during laser beam welding is used to continuously monitor the process and quality properties of the laser-welded products.

Contact: D2 I D4 I D5 I D6

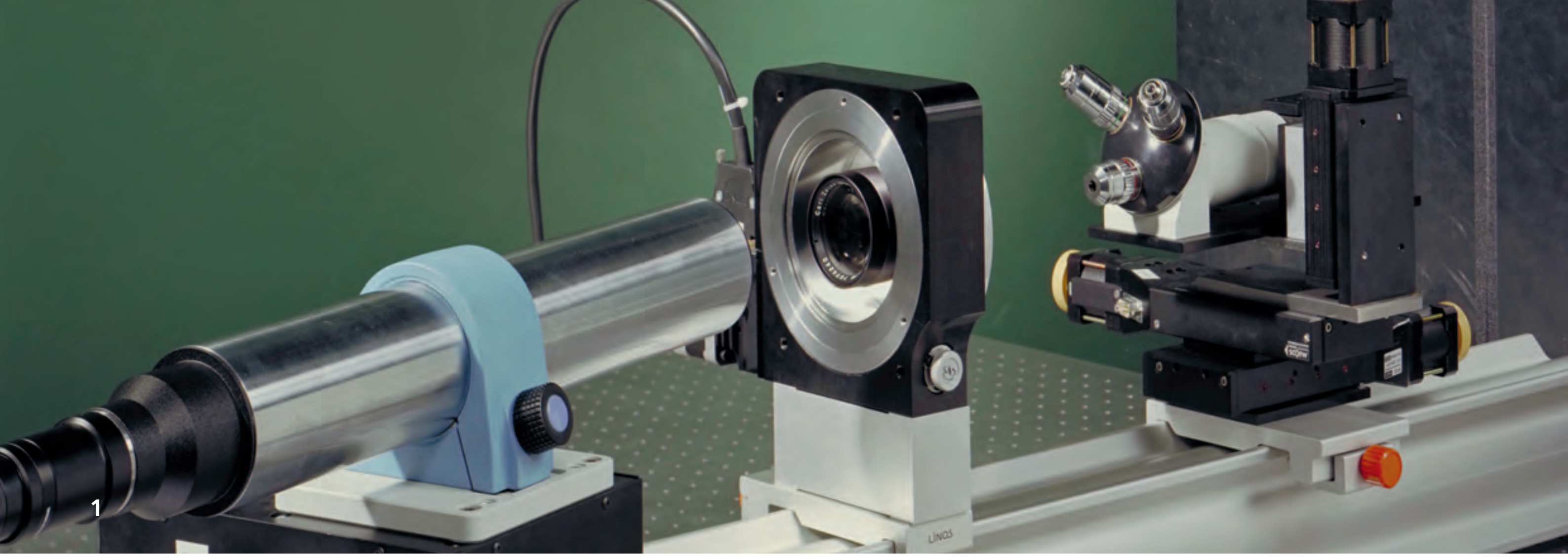
INTEGRATED SENSOR SYSTEMS

Integrated sensor systems play an important role in different application areas. They are subject to special requirements concerning their robustness, reliability and energy efficiency. We offer customer specific adapted solutions for different applications. Two examples on realized applications are given in the next lines.

Custom-tailored optical-spectroscopic sensors for industrial implementations are used for the determination of gas permeation rates of ultra-barrier materials or the characterization of highly porous materials. This includes for example tunable-diode-laser-based permeation rate analyzer to support the developments of high performance coating on foils and polymer webs, or fast non-dispersive IR spectroscopic sensors for material porosity testing.

Gas sensors monitor industrial processes, detect leaks or regulate room climate. Combining gas sensor technology and electronics in compact microsystems that manage on little energy and can be manufactured cost-effectively is the challenge facing the developer. New materials and procedures open up additional applications and markets here for gas Microsystems engineering makes it possible to develop miniaturized gas sensors, system components, and sensor systems as micro-electro-mechanical systems (MEMS) and micro-optoelectro-mechanical systems (MOEMS).

Contact: D3 I D5 I D6



COATING PROCESS MONITORING

Continuous monitoring of long-time running coating processes needs an in-line quality control. An optical monitoring system measures transmission and reflection spectra of coated substrates during the coating process. It gives direct feedback for changes in the properties of a coated film. Important properties such as optical density, visual light transmission, and absorption or color values are calculated from the measured spectra. Thus, necessary adaption of the processes can be made while running the coating task. The system is based on a combination of spectrometers and variable light sources and can be easily adapted to customer specific processes.

Contact: D2

Biophotonic and Medical Sensors

Biophotonic systems and sensors enable the life and environmental sciences to carry out quick and precise analyses. The methods employed here include microscopy, interferometry, spectroscopy, and fluorescence measurement techniques. Such systems have to function autonomously, precisely, and reliably even under adverse operating conditions such as high humidity or temperature fluctuations. Next to medical and environmental applications, some biophotonic methods of detection can also be used for quality control in production. Many substances, including oil and greases as well as wet chemical cleaning agents, are auto-fluorescent and can be detected by fluorescence measuring methods. This way, biophotonics helps to assure the purity and immaculacy of surfaces, which is required in many production processes.

Contact: D4

3D MEASURING SYSTEMS

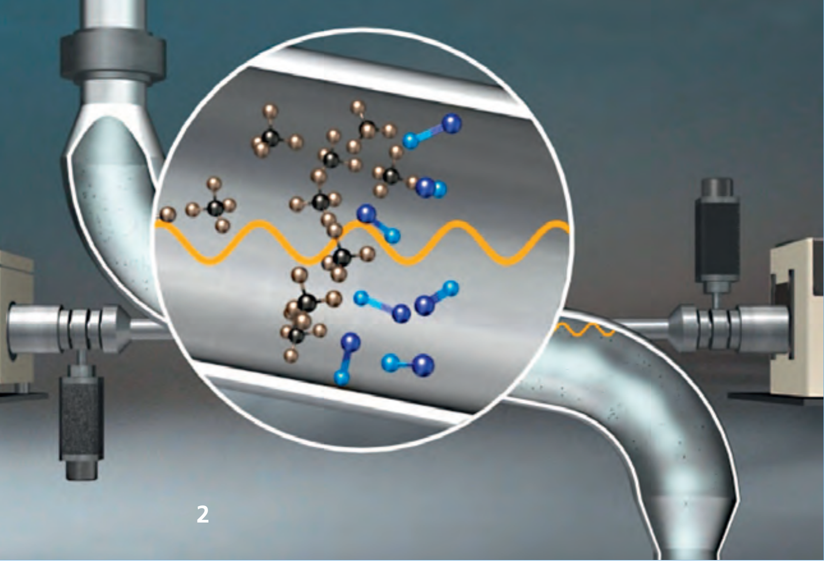
We design and realize optical 3D measuring systems for various applications on the basis of modern 3D measurement techniques (structured light projection, stereo image editing, photogrammetry), laser scanning technology (time-of-flight measurement), digital multi wavelength holography, digital projection technology (LCoS, DMD, OLED), and innovative software and image processing concepts. The application areas of optical 3D measuring systems are broad-based and cover e.g. quality control in tool and mold making, optical industry, mechanical engineering, automotive industry, infrastructure maintenance, medicine, and forensic science.

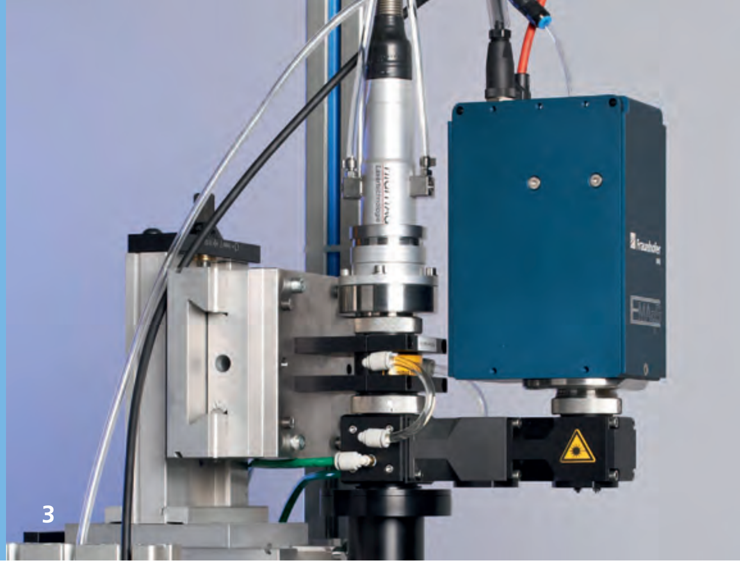
For our customers we supply applied system solutions in which the optical measurement technology can be seamles integrated into automated manufacturing and testing procedures. Examples are handheld optical 3D-scanners, digital multi-wavelength holographic systems, scanners for railway inspection systems, self-calibrating multi-view 3D measurement systems, 3D-high-speed sensor system for precise quality control, and optical 3D digitizing for CAD/CAM in dentistry.

3D measurement puts high demands on camera technology. For lot of applications ultrafast image recording is necessary, with fast change of viewing directions e.g. with micro mirrors. Resolution and recording time can be adapted (as needed), which is especially interesting for applications in the field of machine vision and robotics.

Contact: D5 I D6

1 *MTF measurement system (© Fraunhofer IOF).*





ENVIRONMENTAL MONITORING AND MEASURING SYSTEMS

A major challenge for environmental measurement technology is reliability and sensitivity even under adverse operating conditions. Mostly installed out-doors, the systems should be able to function autonomously, precisely and with low maintenance. The objects to be analyzed range from gases and liquids to aerosols and microorganisms. Suitable measurement techniques include spectroscopy, automated microscopy, interferometry, and auto-fluorescence measurement techniques.

Various systems for environmental monitoring have been realized by the Fraunhofer Group Light & Surfaces. We developed different optical measuring devices for biotic particles in the micrometer range, filter spectrometer for mobile measurement of up to four gases used in blanket emissions monitoring, and spectroscopic exhaust gas measurement technology.

Using our competence and know-how on optical systems, we are able to realize customer specific environmental monitoring and measuring systems.

Contact: D5

2 *Principle of in-situ characterization of multi gas atmospheres (© Fraunhofer IWS).*
3 *Camera based temperature measuring system "E-MAqS" (© Fraunhofer IWS).*
4 *Parcel examination for security control by THz-absorption (© Fraunhofer IOF).*

OPTICS CHARACTERIZATION

Measurement technology is of vital importance for system development and analysis. Components and systems must be consequently characterized and checked on their functionality. For this purpose, we provide measuring setups, such as:

- Modulation transfer function (MTF), focal distance, image scale
- Luminance, near and far field
- Spectrometers
- Laser beam analysis
- Scattered light analysis
- Micro display characterization
- Characterization of LEDs and OLEDs
- Free-form characterization
- Utilization of computer-generated holograms (CGH)
- Waveguide characterization

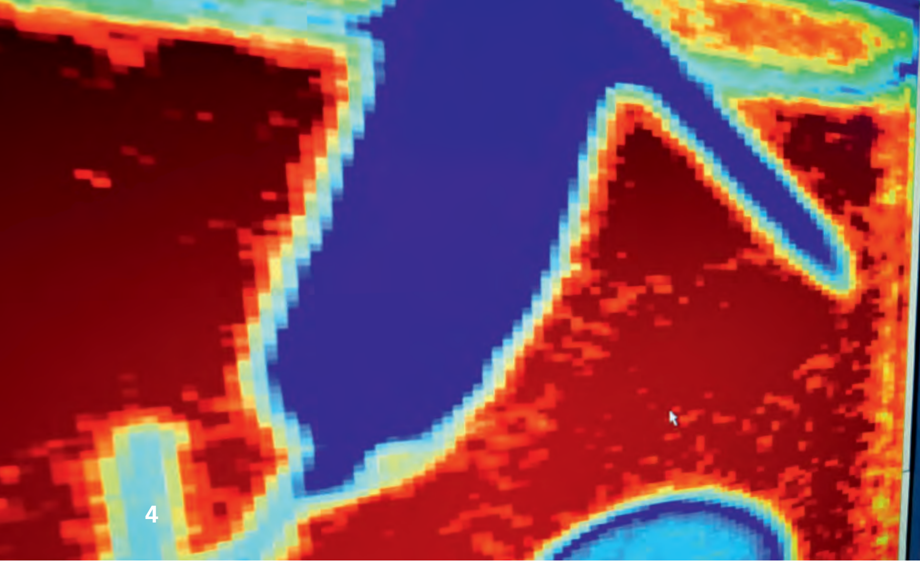
All the acquired data are used in a close loop to the optical design to adapt and/or correct the systems and components if necessary.

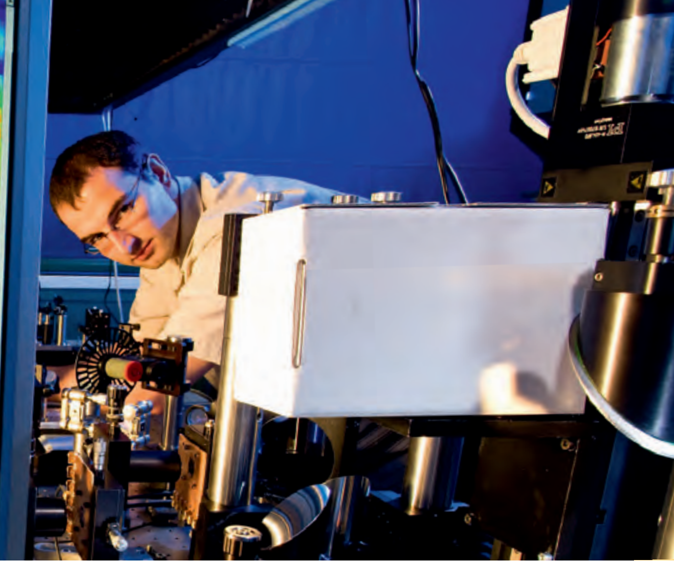
Contact: D6 I D7

LASER BEAM ANALYSIS

The laser beam analysis is an established method for the characterization of brilliant laser beams and laser optics. A 3-dimensional measurement of the intensity distribution at the working position of the laser beam allows determining the beam and image quality of the whole system configuration, consisting of laser source and processing optics, to ensure a high quality of laser materials processing.

Contact: D3





SYSTEMS FOR SURFACE AND COATING CHARACTERIZATION

We have strong experience in the field of surface and thin film characterization. This includes investigations of their composition, film thickness, impurity, homogeneity, nano- and microstructures, optical and functional properties, as well as humidity level. Application-specific investigation programs are designed in order to efficiently support the development of surfaces, coatings, and materials. A comprehensive pool of measurement and analysis tools is available for this purpose. Some examples are:

- Nanostructure and microstructure analysis of surfaces and thin films
- Measurement technology for nano and micro technologies
- Scattered light measurement and analysis
- Light scattering techniques for the characterization of EUV optical components
- UV-VIS-NIR-MIR-THz spectroscopy
- Raman spectroscopy
- VIS spectral photometry
- NIR ellipsometry and hyperspectral imaging
- Test equipment for photocatalytic activity
- Design an analysis of functional surface structures: hydrophobicity, oleophilicity, etc.
- Nanoindentation and nano scratch testing, abrasion, degradation
- Scanning electron microscopy (SEM) and EDX
- Optical monitoring
- Measurement of mechanical thin film stresses

Contact: D1 I D4 I D5 I D6 I D7

TERAHERTZ MEASUREMENT SYSTEMS

The development of powerful emitters and rapid line detectors enables the development of new industrial applications in Terahertz (THz) imaging, THz spectroscopy, THz radar, and THz tomography. We offer the complete design and realization of opto-electronic systems for customer-specific applications. Time-of-flight measurements of ultrashort THz pulses in combination with broadband spectroscopy enable numerous applications in the field of non-destructive material testing, safety and security engineering and tomography. For example examination of closed containers and 3-dimensional reconstruction of components is possible. Terahertz measurement systems have found applications in very different fields:

- Nondestructive testing of insulating materials (cracks, inclusures,...)
- Examination of closed containers (detection of hidden explosive or chemicals)
- Measurement of layer thickness, (e.g. paint or varnish, composite materials, adhesives)
- Analysis of layers (water content, chemical ccomposition,…)
- 3-dimensional reconstruction of components

and much more.

In our TeraTec Applications Center in Kaiserslautern our customers can check and explore what is possible with THz technology.

Contact: D1 I D6

5

METROLOGICAL COMPUTER TOMOGRAPHY

X-ray computer tomography enables the non-destructive detection and recording of the internal and external geometry of an object. Using virtual sections cuts through the object, material testing, the identification of defects and the geometric recording of inner and outer structures are possible. This is performed by full digitalization of the objects, comparison of CT measurement data and CAD model, optimization of CT parameters in terms of close-to-production tests, data evaluation for material testing, adjustment and assembly control/evaluation, consultation for integration in manufacturing processes and quality control loops.

Contact: D6

OPTICAL TIME-DELAY MEASUREMENT

Determining distance from time-delay measurements of laser light is the method of choice in the range from centimeters to several hundred meters when high precision and measuring speed have to be achieved even under difficult and changing environmental conditions. Using the speed of light and the measured time-delay of the light from the light source (emitter) to the object and back to the detector as the basis, it is possible to calculate the distance between measuring head and target object. Laser diodes are generally employed as light sources. High-resolution scanner systems with high measuring rates call for finely focused, high-quality measuring beams. Fast and sensitive avalanche photodiodes (APD) provide the detectors. We employ both pulse delay and phase delay methods.

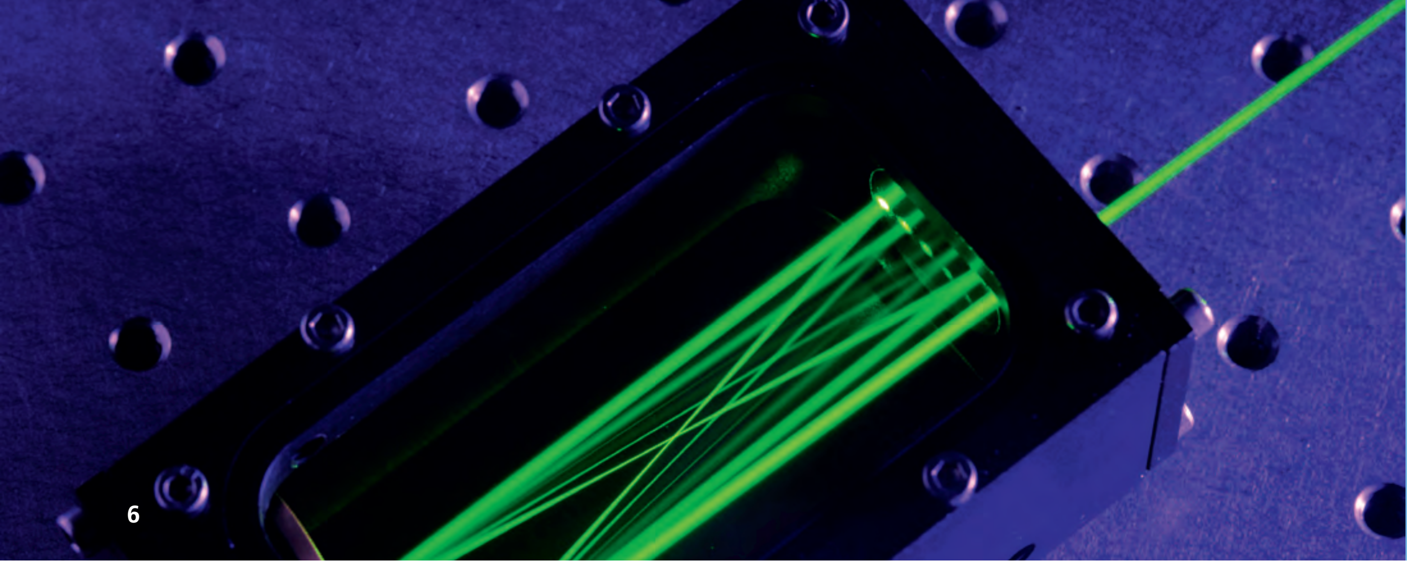
Contact: D5

SPECTROSCOPY

Solids, surfaces, liquids, and gases – the range of materials that can be analyzed by spectroscopic methods is very broad indeed. Using spectroscopic techniques, experts at Fraunhofer detect a wide range of elements by non-contact means. The focus of the Fraunhofer Group Light & Surfaces is on the highly sensitive analysis of gases and gas mixtures using absorption spectroscopy as well as characterization of surfaces and (multi) layer systems with respect to composition, film thickness, impurity, homogeneity and humidity level. Light of a certain wavelength is reflected, scattered, or emitted by a specimen. This takes place in a specific way, according to the chemical substance, thus permitting qualitative and quantitative information to be derived about the compound under investigation. The outstanding advantages of laser spectroscopy are speed and specificity.

The Fraunhofer Group Light & Surfaces has extensive expertise in laser spectroscopy with wavelengths ranging from EUV to MIR and THz. A number of methods such as FTIR, Raman or fluorescence spectroscopy are used. State-of-the-art lasers, laser techniques and measuring procedures are employed according to the measuring task and specimen. Spectroscopic methods of analysis are used for a broad range of applications such as industrial process control, environmental monitoring, biotechnology, space applications, and much more.

Contact: D1 I D5 I D7



TRACKING AND TRACING

The traceability of individual products is proving difficult in times of strongly interlinked chains for production and global supply. For high-priced components, the industry uses RFID labels or data matrix codes for identification purposes. Yet seamless traceability of the production history also makes sense for low-cost products because small components are integrated into large systems where they can cause interference. More cost-effective ”tracking & tracing“ solutions are in demand for small, price-sensitive components, where labels or special markings are technically unfeasible. The Fraunhofer Group Light & Surfaces makes use of individual surface structures for product authentication. The technology is based on the fact that many semi-finished goods or components have an individually distinct microscopic surface structure that can be recognized at production speed with an extremely fast camera-based system. The most distinctive characteristics can be filtered out of the detected surface image and stored in a database as an individual ”fingerprint” of the component along with additional data such as measurements or production details.

Contact: D5

5 *Non-destructive, metrological computer tomography of inside structures (© Fraunhofer IOF).*

6 *White cell for spectroscopic measurement (© Fraunhofer IPM).*

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AEROSPACE AND ASTRONOMY

In aerospace, the Fraunhofer Group Light & Surfaces investigates the design, manufacture, and assembly of modern telescope and spectrometer optics with on-axis and off-axis aspheres, free-form surfaces, and structured surfaces (gratings). Optical systems for earth observation and planetary exploration have been invented, as well as LIDAR systems for detecting the vortex trails of aircraft.

METALLIC TELESCOPE MIRRORS

Mirrors are produced, characterized, and integrated with micrometer precision to ensure their excellent performance; in space applications they have high mechanical and thermal requirements. We realize athermal metallic optics without thermal mismatch. To image space objects with high accuracy, mirror systems (telescopes) are required which offer a maximum of stability and shape accuracy. Furthermore, they must resist the forces present during rocket launch and they must work in sustained continuous operation. Aspheres and optical free forms are becoming more and more important for space applications and astronomy. Applications in the VIS or UV require an ultra-smooth surface quality in terms of figure and roughness. Ultra-precision machining with diamond tools enables the manufacturing of high quality mirrors with various surface shapes in space certified materials.
We performe the mechanical design of the mirrors, the manufacture of aspherical and spherical metallic mirrors with diamond processing, polishing processes, form characterization and correction, coating of the mirrors, assembly, and adjustment of the optics. To improve the optical properties of mirrors coatings made by sputtering techniques are used. This includes, for example, reflecting layers on metallic mirrors from DUV to IR.

One example of realized systems is RapidEye - a satellite system with five identical optical systems for earth observation. It is based on TMA (Three-Mirror Anastigmat) telescopes with two aspherical and one spherical mirror. For the first time, a reflective optical free-form surface with a diameter of 225 mm was developed.

Contact: E2

SPECTROMETERS

The Fraunhofer Group Light & Surfaces develoes reflective infrared spectrometer optics for the MERTIS instrument based on diamond-processed mirrors and a curved optical grating. The spectrometer optics consist of a TMA telescope and an OFFNER spectrometer. For the IR spectral band, the optics are produced ultra-precisely with diamond processing and then coated with gold. The exact system assembly is carried out in modern clean rooms. MERTIS is an instrument of the Bepi Colombo Mission for investigating Mercury.

The spectroscopy of extreme ultraviolet radiation (EUV radiation) helps to explain the cyclical fluctuation of solar intensity and its possible influence on the climatic conditions in the near-earth atmosphere. The SolACES space spectrometer measures EUV radiation with hitherto unrivalled accuracy. Installed on the International Space Station ISS since 2008, it supplies climate researchers with precise data on solar activity. SolACES is the first space spectrometer to be equipped with an auto-calibration system. It therefore achieves extremely low error rates despite the considerable degree of hardware degradation caused by conditions in space.

Particularly powerful solar eruptions are able to cause different problems on Earth, among them interference to radar, navigation, and remote sensing signals. Obtaining a forecast of space weather with the maximum possible precision enables pre-cautions to be taken in time. The Spherical EUV and Plasma Spectrometer (SEPS) measure fluctuations in plasma and radiation from which it is possible to predict space weather. It is intended to form part of a satellite-based sensor network.

Contact: E1 I E2

1 *SEPS sensor, spherical EUV spectrometer (© Fraunhofer IPM).*

1

OPTICAL FILTERS FOR SPACE OPTICS

In some cases specific optical coatings are needed for optical instruments. We offer technologies for the deposition of narrow-band interference filters from UV to NIR spectral range made by magnetron sputtering technology.

Contact: E3 I E4

LIDAR SCANNER

Vortex trails which occur behind aircrafts taking off or landing can represent a considerable danger to following aircrafts. For this task, an x/y scanner with a large aperture and simultaneously high deflection speed was developed. The selected approach enables the offsetting of aircraft movement. The structure was chosen so that the deflective movements are realized with ultraprecise metallic mirrors. Here, the mirrors with limited angle torque motors form the scanner systems.

Contact: E2

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EXTREME WAVELENGTH OPTICS

Whether terahertz spectroscopy or X-ray microscopy, extremely long and short wavelengths are increasingly being used in applications. The services provided by the Fraunhofer Group Light & Surfaces range from optical components and systems for THz imaging to optics for the EUV and the soft X-ray range.

EUV- AND X-RAY-OPTICS

The increasing availability of powerful and brilliant sources for the extreme ultraviolet (EUV) and X-ray spectral region like synchrotron, X-ray free electron lasers (XFEL), and laboratory sources induced optics development for short wavelengths in recent years. Beside the semiconductor industry intends to keep "Moore's Law" alive, continues structure shrinking and pushes worldwide activities to print future computer chips using EUV lithography at an extreme short wavelength of 13.5 nm.

EUV and soft X-ray optics consist of precisely formed and super-polished substrates with up to 1000 thin films having an alternating refractive index such as photons are reflected at each film boundary and constructively interfere. Film thickness varies between a couple of angstroms and a few nanometers with a single layer thickness accuracy of some picometers only.

For over 15 years the Fraunhofer Group Light & Surfaces is pioneering the design, fabrication, and characterization of multilayer and grazing incidence optics for the EUV and soft X-ray region. Current R&D activities focus on EUV lithography applications like laterally graded coatings of large EUV optics up to a diameter of 700 mm, development of multilayers with a superior radiation and thermal stability using thin capping and barrier layers, broadband mirrors, ultrasmooth coatings, and cleaning and refurbishment of EUVL optics. A growing number of non-lithographic activities focus on high-reflective multilayer mirrors for "water window" microscopy, coating of customized synchrotron and XFEL beam line optics and optics for space missions.

Contact: F2 I F3 I F4

EUV AND XUV SOURCES

Pulsed laser sources for EUV generation by laser produced plasma (LPP) as well as direct discharge plasma sources (DPP) are developed and provided as prototypes.

Contact: F2

INFRARED-OPTICS

Reflectors with homogenous illumination and high thermal conductivity as well as mirrors with complex surfaces are manufactured by diamond processing at the Fraunhofer Group Light & Surfaces for a wide range of applications. Typical materials such as copper, aluminum, and silicon can be processed ultra-precisely. For IR applications, the typical requirements of micro-roughness and accuracy of form are realized with direct diamond cutting. Complex surfaces such as aspheres, free forms or lens arrays can be produced simply and precisely using the UP technologies of milling and turning. The processed metal surfaces are optically finished. Particularly outstanding properties in the NIR and IR ranges are achieved using sputtered gold layers. Reflective and transmissive applications in the fields of aerospace, safety, and defense technology are the subject of research and development at the Fraunhofer Group Light & Surfaces, as well as the development of particularly compact and robust systems for IR spectroscopy.

Contact: F4

1

TERAHERTZ-OPTICS

Terahertz radiation (λ=3 mm - 30 µm, 0,1 - 10 THz) is low in photon energy and therefore not harmful. It penetrates major types of plastics, paper, clothing, and semiconductors. However, it is absorbed by water and reflected by metal. Moreover, the molecules of many organic substances, medication, illegal drugs, and explosives have rotational transitions that can be detected and identified with THz radiation.

Within the Fraunhofer Group Light & Surfaces, different THz systems have been developed: THz spectrometer, mobile THz scanner for the non-destructive testing, and THz tomograph. All systems require specially designed and manufactured THz optics, such as metallic mirrors, asphehrical lenses (materials for example ZERODUR). The Fraunhofer Group Light & Surfaces offers complete systems, optical components, and applications/measurments to its customers.

In our TeraTec: Terahertz technology applications center in Kaiserslautern our customers can check and explore what is possible with THz technology.

Contact: F1

1 *Largest Mo/Si multilayer optics to date: 660 mm EUV lithography collector mirror for high-power laser produced plasma sources (© Fraunhofer IOF).*

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LASER BEAM SHAPING AND DELIVERY

The use of laser and laser diode sources in metrology, visualization, and materials processing requires beam shaping optics on the one hand for production (collimation, circularization, and astigmatism correction), on the other hand for adaption to specific tasks (focusing, line and pattern generators, etc.). The Fraunhofer Group Light & Surfaces develops optical designs and adapted set-up and assembly technologies. In addition, special optical elements are manufactured for beam shaping systems.

LASER BEAM SHAPING

For most laser application, a tailored intensity distribution is demanded to meet the specific goals defined by the application. As the spatial intensity distribution of the laser source usually does not meet the requirements set by the application, sophisticated beam shaping techniques have to be applied. The desired intensity distribution is usually derived from experimental studies or complex finite element modeling. Traditional laser beam shaping includes the generation of customized intensity profiles by homogenization or prisms. Recent devel-opments in this field depend on diffractive optical elements (DOEs) and freeform optics which are designed by the Fraunhofer Group Light & Surfaces. As those optics are mainly used for material processing applications, the choice of the optical material and the thermo-mechanical design of the optical system is of great importance for the successful setup of a reliable high performance optical system.

Contact: G1 I G2 I G5

LASER BEAM DELIVERY

One of the main advantages of lasers compared to conventional manufacturing technologies is the lack of inertia of the tool. To benefit from this fact, the laser beam has to be delivered by a flexible, robust, and lightweight component to the work piece. Due to the emitted wavelength, the radiation of solid state lasers and diode lasers can be delivered by using optical fibers. Especially for high power diode laser systems, efficient fiber coupling depends on a sophisticated analysis of the optical system used for beam shaping and transformation. Within the Fraunhofer Group Light & Surfaces we develop adapted beam delivery systems to enable customers various applications.

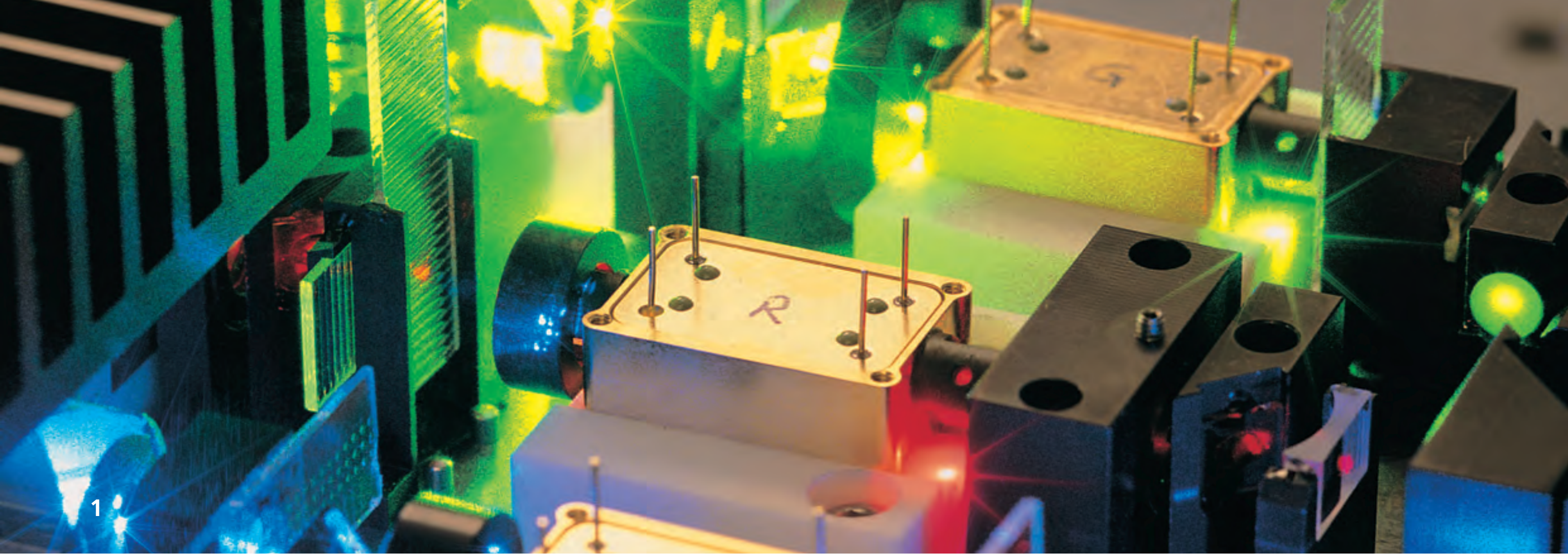
Contact: G1 I G2 I G5

BEAM COUPLING

High-power diode lasers are well established as pump sources for solid state and fiber lasers, for material processing and medical applications. Major advantages of diode lasers compared to solid state and gas lasers are very high wall plug efficiency, compact size and cost efficiency. However, those devices do not offer the high radiance of solid state and fiber lasers.

To scale the radiance of diode lasers, different beam coupling techniques have been developed. Polarization multiplexing increases the radiance by a factor of two, while wavelength multiplexing is only limited by the number of wave-lengths available if a reduced spectral radiance is acceptable. By using dense wavelength multiplexing schemes for high power diode laser systems, the radiance of solid state lasers will be achievable.

Contact: G3



CHIRPED MICRO LENS ARRAYS FOR RGB-LASER MODULE

One crucial component of digital minilabs for photofinishing is the exposure unit using a modulated RGB laser source. We built a miniaturized source based on frequency-doubled solid state lasers. Because waist size tolerances of the sources exceed the writing spot specs, the anamorphic imaging optics compensates for these tolerances using zoomable micro-optical beam expanders.

One element of such a two-lens beam expander is a lenslet of an array with chirped focal width. Thus, beam expansion is adjusted by selecting the proper lenslet. Further important features of the RGB source are active pointing stabilization of the solid state lasers by piezo-driven beam steering and power control for each channel to exploit the full dynamic range of the modulators. The chirped lens arrays are manufactured by replication of circular and cylindrical reflow lens arrays. The micro-optical components together with the stock lenses and the active components are mounted on a stainless steel motherboard, which is shaped to fit into the laser scanning unit of an existing minilab.

Contact: G1 I G2

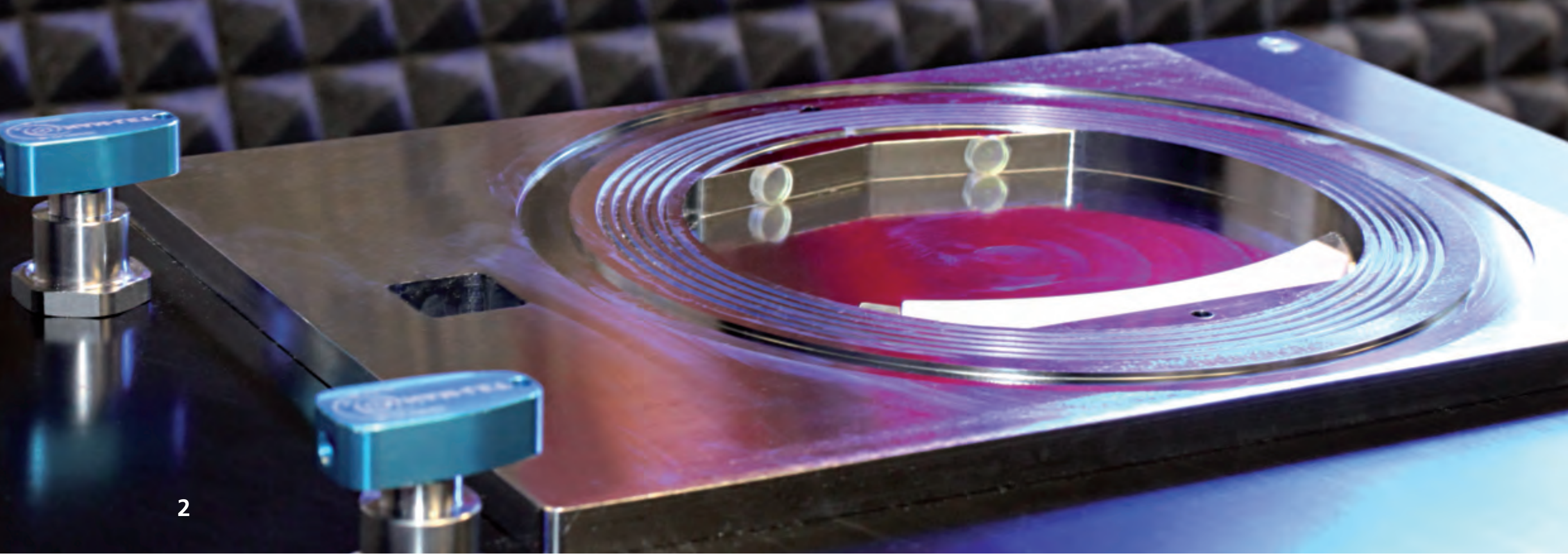
MICROOPTICS FOR MODE AND BEAM SHAPING OF LASER RESONATORS

The focus spot size and the divergence of a laser beam are defined by the transversal modes of the resonator. A modification of the outcoupled beam can be realized by intracavity beam shaping which allows an adaption of the laser beam properties to special applications.

Aspherically shaped mirrors influence the form of the existing modes and may increase the discrimination of higher-order modes. Laser resonators comprising high performance optics enable an adaption of mode volume to pumped volume and a high beam quality for lasers with high gain. In addition, the compensation of interactions by nonlinear effects of the active media with the intracavity optical field becomes possible.

Contact: G5

1 *RGB-laser source prototype (© Fraunhofer IOF).*



2

CONTROLLING THE PROPAGATION OF ULTRASHORT LASER PULSES

The extreme intensities which can be achieved by focusing ultrashort laser pulses, make them very interesting, e.g. for materials processing. The spatial and temporal field distribution of a laser pulse significantly affects the achievable power in the focus of optics. Therefore, it is essential to know the field distribution and, if necessary, be able to change it adequately. The field distributions of ultrashort laser pulses can be considerably improved and optimally adapted to specific applications by using appropriate tools for design and analysis. Numerical simulations serve as the basis for analysis of arbitrary optical systems and design of customized optics.

The manipulation of the spatial and temporal field distributions of the laser pulses is accomplished by means of suitable phase elements.

Contact: G2 I G5

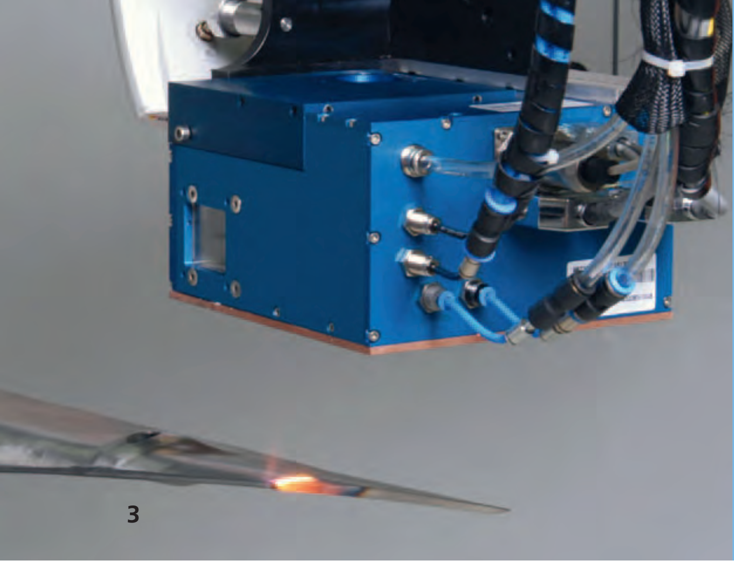
HOMOGENIZATION OF POWER DENSITY DISTRIBUTIONS

Applications like hardening and illumination suffer from the undefined farfield distribution of most commercially available high-power diode laser stacks being a major drawback of these devices. As single emitters and bars can fail during their lifetime, the near-field distribution does not remain constant. To overcome these problems, the intensity distribution can be homogenized by a waveguide or by microoptic devices.

The waveguide segments the far-field distribution by several total internal reflections, and these segments are overlaid at the wave-guide's exit surface. By the microoptic device, the near field is divided into beamlets which are overlaid by a field lens. Both approaches can be used for one and two dimensional homogenization of high-power laser systems.

Contact: G2 I G5

2 *Laserbased permeation rate analyzing chamber (© Fraunhofer IWS).*
3 *Dynamic beam shaping system "LASSY" (© Fraunhofer IWS).*
4 *Beam delivery with highspeed laser beam scanning system lasertronic® SAO (© Fraunhofer IWS).*



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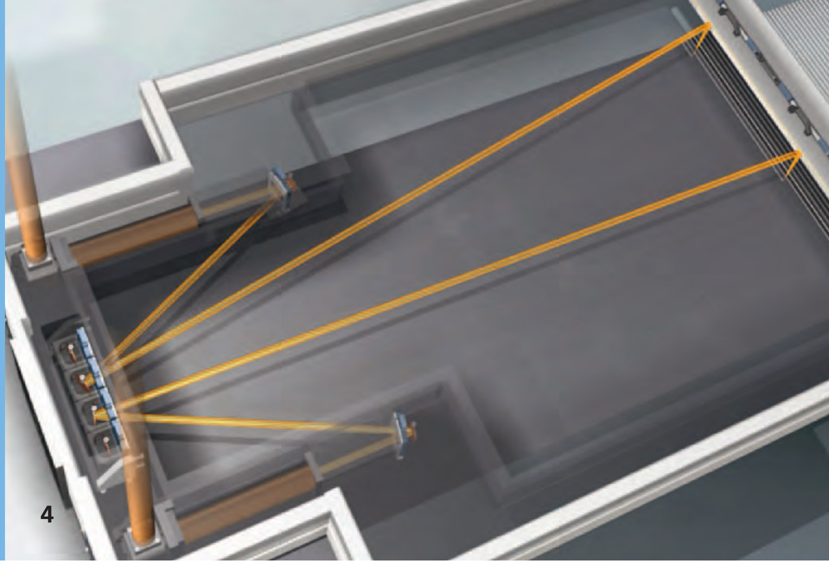

4

PROCESS OPTICS

In addition to the classical requirements upon the design of optical systems, such as diffraction-limited imaging and focussing, the generation of process-adapted power density distributions is gaining significance. The integration of coaxial process monitoring increases the functionality of the process optics and helps to improve the process stability. Intelligent optical systems can be generated by connecting conventional optics with innovative beam forming elements and open up a wide range of applications. The implementation of these designs in robust and industry-ready prototypes rounds off the development of optical systems.

Contact: G1 I G4

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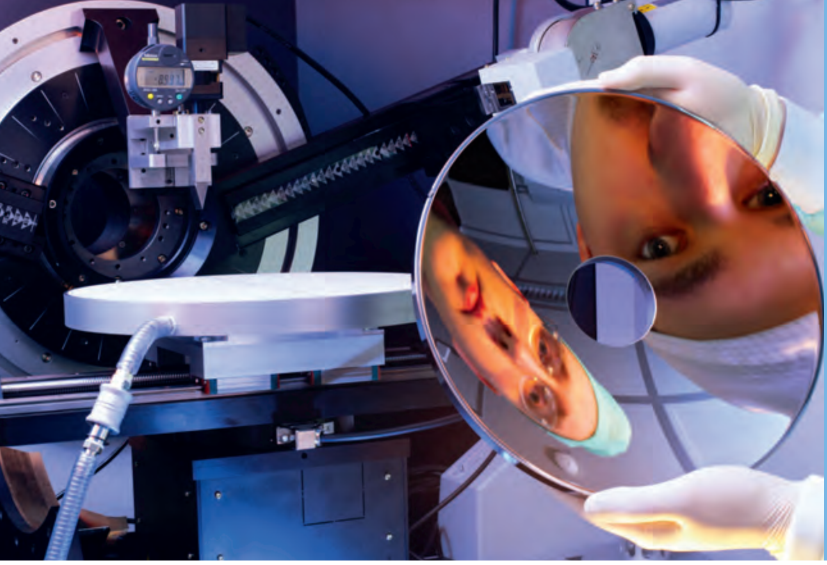



FRAUNHOFER GROUP LIGHT & SURFACES

Six Fraunhofer institutes cooperate in the Fraunhofer Group Light & Surfaces. Coordinated competences allow quick and flexible alignment of research work on the requirements of different fields of application to answer actual and future challenges, especially in the fields of energy, environment, production, information and security. This market-oriented approach ensures an even wider range of services and creates synergetic effects for the benefit of our customers.

CORE COMPETENCES OF THE GROUP

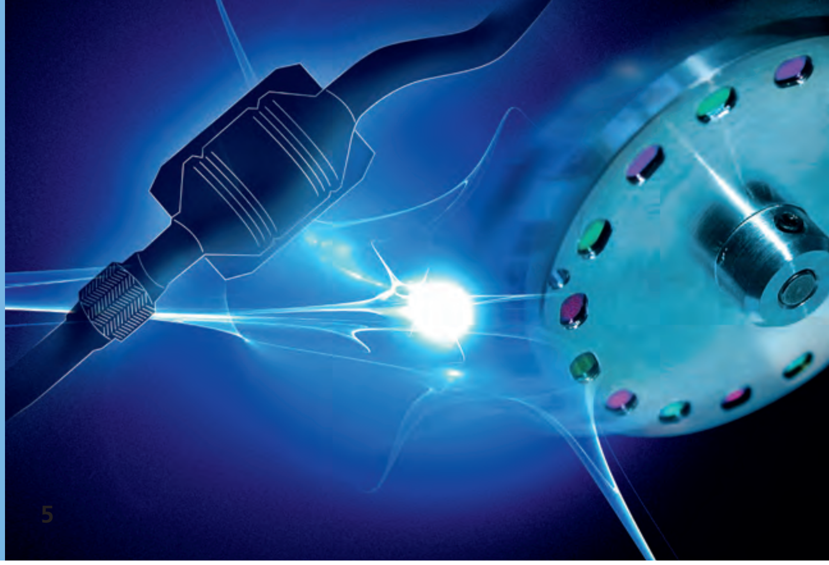
- Surface and coating functionalization
- Laser-based manufacturing processes
- Laser development
- Materials in optics and photonics
- Microassembly and system integration
- Micro and nano technology
- Carbon technology
- Measurement methods and characterization
- Ultra precision engineering
- Material technology
- Plasma and electron beam sources

FRAUNHOFER INSTITUTE FOR ELECTRON BEAM AND PLASMA TECHNOLOGY FEP

Electron beam technology, sputtering technology, plasma activated high-rate deposition and high-rate PECVD are the core areas of expertise of Fraunhofer FEP. The business units include vacuum coating, surface modification and treatment with electrons and plasmas. Besides developing layer systems, products and technologies, another main area of work is the scale-up of technologies for coating and treatment of large areas at high productivity.
www.fep.fraunhofer.de

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

The Fraunhofer Institute for Material and Beam Technology is known for its innovations in the business areas joining and cutting as well as in the surface and coating technology. Our special feature is the expertise of our scientists in combining the profound know-how in materials engineering with the extensive experience in developing system technologies. Every year, numerous solution systems have been developed and have found their way into industrial applications.
www.iws.fraunhofer.de



FRAUNHOFER INSTITUTE FOR APPLIED OPTICS AND PRECISION ENGINEERING IOF

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